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Running Head: BLACK HOLE ILLUSION

Visual Spatial Disorientation:

Re-Visiting the Black Hole Illusion

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ABSTRACT

Visual spatial disorientation (SD) is cited often as a contributor to aviation accidents. The black hole illusion (BHI), a specific type of featureless terrain illusion, is a leading type of visual SD experienced by pilots. A BHI environment refers not to the landing runway but the environment surrounding the runway and the lack of ecological cues for a pilot to proceed visually. The problem is that pilots, despite the lack of visual cues, confidently proceed with a visual approach. The featureless landing environment may induce a pilot into feeling steep (above the correct glide path) and over-estimate their perceived angle of descent (PAD) to the runway. Consequently, a pilot may initiate an unnecessary and aggressive descent resulting in an approach angle far too shallow (below the correct glide path to landing) to guarantee obstacle clearance. This review addresses two questions. One, why do pilots over-estimate their PAD? And two, if visual SD is such a well-researched and documented phenomenon, why does visual SD still continue to contribute to aviation accidents today? Based on previous research, eight reasons are hypothesized as why a pilot over-estimates PAD. Also, a historical review of the BHI is presented as well as a discussion of past research and accident investigations that demonstrate inconsistencies regarding the state of the BHI.

Accidents do not occur because people gamble and lose, they occur because people do not believe that the accident about to occur is at all possible. (66, p. 596)

Different types of mishaps can be classified in terms of the pilot(s) and/or aircraft status at the time of the accident. The leading cause of fatalities (4), controlled flight into terrain (CFIT), is defined as an otherwise airworthy aircraft flown by a pilot impacting terrain or man-made obstacle. The actions or in-actions of the pilot(s) and the performance-state of the aircraft are investigated to learn about the contributing factors leading to the accident. According to a Boeing study of worldwide commercial airline accidents, the approach and landing phase of flying, although only accounting for 4% of the total flight time, accounts for 52% of all accidents/fatalities; of those, 55% are due to flight crew error (4). Khatwa and Helmreich (30) reported that out of 287 worldwide aviation accidents between 1980-1996, more than 75% of approach and landing accidents (ALA) happened when a precision approach aid (glide path, GP) was not available or not used. They also found that the rate for an ALA at night was approximately three times the rate during daylight.

Spatial disorientation (SD) is defined by Gillingham (21) as, "an erroneous sense of one's position and motion relative to the plane of the earth's surface" (p. 297). Furthermore, pilot SD refers to incorrect perception in magnitude/direction of any of the aircraft control and performance flight parameters, such as altitude and vertical velocity (21). An analysis of United States Air Force (USAF) SD mishaps from 1990 – 2004 found that of all mishaps, 11% are attributed to SD and that SD accounts for 23% of accidents occurring at night (37).

In 2000, a survey of 141 students at the USAF Advanced Instrument Course (graduate type course for experienced pilots) found 79% of pilots reported the black hole illusions (BHI) was the second most common occurrence of a possible 38 visual/vestibular types of SD (62). In 2002, another study surveyed 2,582 USAF pilots and their experiences with SD (38). Their

survey found that the leading cause of visual SD in multi-engine aircraft was the BHI. For all types of USAF aircraft, the BHI was the third most cited type of visual SD.

The BHI can be thought of as a specific form of a featureless terrain illusion. The United States Department of Transportation (US DoT) defines the featureless terrain illusion as:

> An absence of ground features, as when landing over water, darkened areas, and terrain made featureless by snow, can create the illusion that the aircraft is at a higher altitude than it actually is. The pilot who does not recognize this illusion will fly a lower approach. (64, p. 8-1-6)

Visual SD received research attention in the late 1960s, 1970s and 1980s. Mishaps dating back 30-40 years however are not that different from a series of mishaps that occurred in recent times. Hasbrook (29), in 1975 summarized visual approach problems in aviation and the number of accidents:

> From these dreary facts, it appears that pilot perception of the approach path is often seriously in error. Whether such error is due to a lack of needed visual cues (particularly at night), visual illusions, lack of knowledge of available cues, potential error-producing visual concepts or a combination of these, is a question that has been studied many times, but still awaits an answer. (p. 39)

Unfortunately, deep understanding of the problem still awaits us thirty years since Hasbrook's assessment. The focus of this paper is a review of visual perception in aviation and the role of black hole (BH) approach environments in CFIT accidents.

EARLY ACCIDENTS ATTRIBUTED TO VISUAL SPATIAL DISORIENTATION

Kraft (31) described four night visual, landing airline accidents.

1. In 1965, a United Airlines Boeing 727 departed 6,706 m for a visual night descent into Chicago. The aircraft continued its descent, failed to level off and consequently impacted Lake Michigan 30.6 km off shore.
2. In 1965, an American Airlines aircraft flying into Cincinnati, OH, for a night approach and landing impacted a ridgeline just prior to the runway.
3. In 1966, a United Airlines aircraft descended too steeply during a night approach over dark terrain/water and landed short of the runway near Salt Lake City, UT.
4. In 1966, an All Nippon Airways Boeing 727 commercial airliner crashed 10.5 km short from the Tokyo airport into Tokyo Bay.

Another commercial airline accident occurred in January, 1974, at Pago Pago International Airport, American Somoa. A Pan American World Airways, Boeing 707 aircraft, crashed 1,025 m short of Runway 05 (46). The National Transportation Safety Board (NTSB) found that the probable cause of the accident was failure to recognize an excessive descent rate while making the final approach to landing. Contributing to the accident and delaying any attempt by the aircrew to correct the descent rate were weather conditions and a BHI. Only 5 of the 101 persons on board survived the crash. There were visual approach slope indicator (VASI) lights on the 2,743 x 46 m runway (length:width ratio of 60), but the first officer who survived the crash didn't recall seeing them. The pilot reported the "runway in sight" at 12.8 km and repeated this five more times.

The misperception of height and distance is a common occurrence in BH approach accidents (43, 44, 55, 57, 58). Although visual cues are impoverished and perceptual capabilities limited, pilots trust out-the-window cues rather than relying on instruments because they place too much confidence in their visual perception even when cues are lacking (23). In rich viewing

environments to familiar airfields, the perceived angle of descent (PAD) equals the actual angle of descent to the runway and if there is a disconnect, sufficient visual cues are available for ecological feedback (too shallow or too steep) and timely correction. In a featureless environment however, while assessing their GP, pilots may over-estimate their PAD. Consequently, trusting their perceptual abilities, pilots initiate an overly aggressive descent and incorrectly adjust below the desired GP.

In 1991, it was reported that three aircraft landing at the same airfield on the same night all fell victim to featureless terrain illusion (14). Each airplane experienced similar illusions and landed shorter than the previous aircraft. The third and final aircraft impacted the terrain 457 m short of the landing runway and suffered substantial damage. In October 1991, a Canadian Air Force C-130 crashed short of the runway on Ellesmere Island, the northern most island in the Canadian Arctic. In 1993, Robert Mason Lee wrote a book describing the accident and survival of the crew/passengers entitled, *Death and Deliverance* and in 1997 a movie was made based on the book called, *Ordeal in the Arctic*. CFIT resulted when the pilot abandoned his instruments and proceeded visually to the runway in a BH approach environment. While viewing the movie one gets the feeling that an accident of that type could not occur anymore due to today's advanced aviation systems.

CURRENT ACCIDENTS ATTRIBUTED TO VISUAL SPATIAL DISORIENTATION

Many visual SD-caused aviation accidents are considered "classics" in that they happened decades ago. The aviation community seems to have a false sense of security believing that due to superior education and technology those types of older-generation accidents cannot possibly still occur. Unfortunately, that is not the case. For example, in 1996, a Delta Airlines aircraft sustained substantial damage when it impacted an approach light structure

during an approach to landing on Runway 13 at LaGuardia Airport, NY (48). The approach to Runway 13 brings aircraft in over the water to landing. The pilots were transitioning to a visual landing after flying an instrument approach. The NTSB report addressed the featureless terrain illusion due to the absence of visible ground features. Consequently, the pilot erroneously perceived his position as being higher than it actually was (incorrect PAD) and induced an overly aggressive descent the last 10 seconds of the approach.

In 1997, a Cessna flying for Air Sunshine crashed into the Caribbean Sea 4.8 km southwest of St. Thomas Virgin Islands (50). Two passengers were killed while three others survived. The NTSB report concluded:

> Evidence suggests that the absence of visual cues caused by the combination of dark sky and darkness over the water produced a "black hole" effect in which the pilot lost visual sense of the airplane's height above the water. As a result, the pilot misjudged the airplane's distance form the island and height above the water. (p. 1)

In 1997, a $60 million Boeing 747-300 impacted Nimitz Hill, 6.1 km short of Runway 06L, at A.B. Won Guam International Airport, Guam (49). Of 254 persons on board, 228 did not survive. Although the NTSB found the probable cause of the accident was an improperly briefed and flown non-precision approach as well as the aircrew's failure to monitor the approach, there was in-direct mention of SD. The pilot expected to fly a visual approach and consequently failed to adequately brief the instrument approach procedure. As a result, there was confusion regarding the status of the navigation systems. Listed in "findings," the NTSB alluded to SD by stating the pilot may have lost situational awareness regarding his position relative to the runway, believing he was closer than he actually was. Whether this was due to a lack of understanding of the non-precision approach or to visual SD is not addressed in the report.

Nowhere in the NTSB report is the BHI mentioned, however the approach late that rainy night brought the aircraft in over water and mountainous terrain and into an area of Guam called the "black hole" (e.g., 53). The NTSB report acknowledged pilots' tendencies to expect visual approaches into Guam and the fact that this aircrew expected the weather to allow for a visual approach. Runway 06L was 3,053 x 46 m (length:width ratio of 67) and up-sloped, rising 13 m from landing to departure end. The high ratio of a long-narrow runway (34, 43, 44) combined with an up-sloped runway (31) may also have been conducive to producing a shallow approach. Furthermore, a shallow approach to landing at Runway 06L at Guam is more dangerous due to the mountainous terrain. The 747 crashed into Nimitz Hill, which sits 204 m above sea level, enroute to the airport that has a field elevation of 91 m above sea level.

In 1999, a USAF C-130 aircraft flying a night visual approach crashed 881 m short of Runway 15R at Al Jaber Air Base in Kuwait, killing 3 people (1). The cause of the mishap was found to be pilot error. The pilots were cited for failing to follow directives as well as complacency in flight operations that resulted in SD during the visual approach. Consequently, this all led to a loss of situational awareness regarding the aircraft's excessive descent rate. The Accident Investigation Board (AIB) stated that the aircraft's final approach initially was 3 degrees but soon became too steep (6 to 7 degrees GP) and failed to return to the normal GP prior to landing. Though not specifically stated in the AIB, flying at night in a featureless desert environment would be conducive to a BH atmosphere and the approach as described is similar to a BH concave approach.

Also in 1999, an Air Canada Airbus A320 flying a night approach into St. John's Newfoundland airport impacted 76 m short of the landing threshold (63). No VASIs were present and pilots that had previously flown into that runway reported BH conditions.

In 2001, a chartered Dassault Falcon 20 cargo flight struck terrain 8.3 km from Runway 07 during a night visual approach killing all three aboard in Narsarsuaq, Greenland (16). The Danish Aircraft Accident Investigation Board determined that the pilot elected to fly a visual approach rather than the instrument approach and failed to maintain vertical awareness to the terrain. The flight crew focused on visual contact with the runway, experienced the BHI and consequently, flew a shallow approach resulting in CFIT.

In 2002, a Boeing 727, operated by Federal Express (FedEx) struck trees on short final approach prior to sunrise and crashed 472 m short of Runway 09 at Tallahassee Regional Airport (51). Three crewmembers were seriously injured and the airplane was destroyed. Runway 09 did have precision approach path indicator (PAPI) lights available to assist in GP control. As the pilot maneuvered the airplane into alignment with the runway their GP decreased below the desired 3 degree GP. The profile of this approach depicted a concave shape found in the BHI (17).

In examining the profile of the aircraft's descent rate, it seems likely that a BHI induced the pilot to misperceive the GP (over-estimate PAD) from 10.1 km from the runway until impact (17). The final approach to Runway 09 has the aircraft flying over a national forest area totally devoid of lights or terrain features. On final approach the airplane had a descent rate of 380 m/minute; nearly twice what it should have been. The PAPI lights for the approach, providing feedback of visual GP, showed below GP from the 8.3 km from the runway to well below GP at the 5.6 km point. Procedurally, any below GP indication should be immediately followed with a positive correction. All crewmembers stated that they were shocked upon hitting the ground; despite the PAPI indications, none of the pilots perceived their GP to be below normal. In their

conclusion, the NTSB determined the probable cause was "failure to establish and maintain proper glidepath during the night visual approach to landing" (51, p. 68).

A recent incident, in May 2006, a two-seat F-16 aircraft came within 6 m of the ground 0.9 km from the intended runway (10). The pilots were flying a practice night visual approach into a dark auxiliary airfield that lacked an approach lighting system but did have PAPIs. Contributing to the incident were mis-prioritization of tasks and failing to monitor and challenge the flying pilot. These factors were exacerbated however, by a featureless terrain that may have allowed the pilot to perceive a "duck under" maneuver (shortening desired aimpoint) as safe to accomplish (10); or the landing environment induced the pilot into over-estimating his PAD.

Examining these most recent black hole mishaps reveals a disturbing trend of pilots "going visual" and trusting their visual capabilities in spite of impoverished viewing conditions. Specifically, the 1997 crashes in St. Thomas and Guam, the 1999 C-130 crash in Kuwait, the 2002 FedEx accident in Tallahassee, and the F-16 incident this past year all suggest that the respective pilots, no differently than the pilots at Pago Pago in 1974, gave too much credence to their ecological perception.

WELL-RESEARCHED & DOCUMENTED PHENOMENON?

As I have described so far, the phrase "black hole" is often mentioned in today's accident investigation reports. Research over the years has presented varying explanations regarding the cause of the BHI and at what distance it occurs from the runway. One common concept found throughout the discussion of the BHI is that pilots report that they over-estimate their PAD and unknowingly and incorrectly attempt to adjust to an unsafe, dangerously shallow GP.

Why the Misperception of PAD?

There have been many descriptive narratives regarding the BHI and different environmental situations causing a pilot to error in their PAD. Below is a summary of hypothesized reasons that collectively or individually may contribute to a pilot's over-estimation of PAD, thus inducing an unwarranted and unsafe excessive descent resulting in a dangerously low and shallow GP to the runway. This list demonstrates unresolved BHI issues.

1 – Size/Shape/Depth Constancy: A runway which appears to be long and narrow produces a feeling of being too steep based on retinal image size and shape. Normally a long and narrow runway is seen when a pilot is high and far from a runway. The ability of a pilot to use perceptual constancy as a cue is greatly reduced because it is difficult to relate the 2D retinal image to a 3D object due to a lack of ambient vision cues (28, 39, 42, 43, 55, 58). Shape and depth retinal interpretations relate to Gibson's (20) description of foreshortened surfaces.

2 – Lack of Familiar/Relative Size: Featureless terrain lacks both global and local objects for retinal size comparison removing the ability to confirm accurate retinal size (7, 8, 39).

3 – Bias to Over-estimate Visual Angles in the Medial Extent: Prior knowledge of a long runway (a 2.4 km runway for example) conflicts with the apparently small visual angle in the medial extent. The result is an over-estimation of the medial visual angle based on the retinal image combined with knowledge of its actual length-in-depth (13). Consequently, the bias to perceive the runway image as longer than it actual is further promotes the appearance of it relative to item-1 above (size/shape/depth constancy) and contributes to an error in PAD.

Crassini, et al. (13) argued that an object takes on varying geometrical interpretations dependent upon the subtended visual angle and orientation-in-depth produced from different lines-of-sight. During flying this phenomenon would affect the GP angle as viewed toward the runway. For extremely shallow visual angles in the medial direction foreshortened to account

for depth, objects look longer because a form of over-compensation by the perceptual mechanisms. This may result in perceiving the runway to look longer, and it if looks long, then for a given position from the runway, the pilot may over-estimate PAD. Haber (25) found subjects underestimated radial distances. Thus when combined with a bias to overestimate a runway's length, the feeling of being steep and too close to the runway may induce a pilot to initiate a descent.

4 – Lack of Terrain Orientation Cues: A lack of global and local objects or terrain features fails to produce the perception of the runway as a surface plane on the ground (7, 8, 19). This lack of orientation allows the runway to "float" making it difficult to determine the approaching aircraft's height above the ground, the distance to the runway, and a proper perception of depth. Also, in this environment of impoverished cues, there are no relative retinal comparisons required for size, shape, and depth constancy (see item-1). Finally, terrain orientation is vital for the perception of the "array of adjoining surfaces" defined by Gibson (20) and the BH environment lacks visual space array information of the surfaces. Perrone's (57) form ratio theory also supports this reason due to a lack of perspective information.

5 – Lack of Distance Cues: Related with previously mentioned hypothesis, in the absence of distance cues (global and local features), the size/shape/depth constancy of the runway cannot be properly perceived (22, 39, 55, 59).

6 – Optical Slant versus Geographical Slat: Geographic slant, slope of the terrain (59), involves both optical slant and perception of height or angular position (40). Since distance, depth, and orientation cues are absent, geographic slant cannot be perceived resulting in optical slant as the sole remaining cue to actual slant. Optical slant however is based on line-of-sight relative to the surface (40) and the surface is not available during a BH approach; thus, optical

slant is not an adequate cue. Also, Mertens (41) found subjects over-estimated this optical slant value.

7 – Approach Lighting Systems (ALSs): ALSs were developed to extend the runway environment towards the pilot during the transition from instrument to visual conditions in low visibility environments. Acquiring the runway image and flying a night visual approach to landing using the ALS in good visibility at night however may perceptually increase the apparent runway ratio, causing the runway to appear narrower. Thus, further promoting the feeling a steep PAD and may result in initiation of an excessive descent enroute to a dangerously shallow approach (45, 57).

8 – Equidistance Tendency: According to Gogel (22), this equidistance tendency occurs when objects appearing together are perceived at the same distance when other visual cues are absent. For slanted-in-depth objects, the equidistance favors the foreshortened, frontal plane – resulting in a perception of slant over-estimation. This explanation is related to the lack of distance cues and familiar/relative size cues.

Research Origins of the "Black Hole" Concept

Although the specific use of the phrase BHI was not always stated, the description of the phenomenon has been present for some time. In 1947, Vinacke (65) presented a detailed list of illusions experienced by pilots. Under the discussion of visual illusions, he presented the problem of depth perception when flying over smooth water or on a "black night" resulting in problems of landing and judging height above the terrain. The term BH however was not used.

Calvert (7) described visual illusions when landing an airplane in reference to improving visual aids, runway and runway approach lights for pilots to improve night landings. He described a common illusion when the runway lights appear to "float in space" and "stand on

end" (7). Calvert, however did not use the term BH in 1950, but he did in 1954 describing the importance of features in a visual field for controlling actions and the critical role of a ground plane for visual reference (8). He may have been the first to describe the BH, "few things are more trying than a uniform environment with no horizon or texture, whether one is skiing in a snowstorm, or flying into the 'black hole', which is the runway as it appears on a misty night" (p. 235). Calvert (9) referenced the phrase "black hole effect" regarding a height just 22.8 m above the ground when transitioning from instrument to visual conditions (p. 280).

In 1953, Cocquyt (12) addressed pilot error in aviation accidents. His perspective was that optical illusions played a role in mishaps and more research and education of pilots needs to occur. Cocquyt did not use the phrase BHI, but did describe a similar illusion of a pilot having the sensation of flying higher than he actually was (steep PAD) based on a perceived positive imaginary height of the runway compared to the actual runway ground plane.

In 1958, Wulfeck, Weisz, and Raben (70) discussed all aspects of vision in military aviation but did not use the term BH. They did address a "no contrast environment" or "white out condition" (featureless terrain aspects) in some landings but made no mention of the term for nighttime BHI. The authors did mention varying widths and lengths of runways and those longer or narrower runways could induce shallow approaches.

In 1966, Kuhlman (33) gave advice to pilots in his article and emphasized not flying a straight-in approach at night to a runway. His explanation was based on the idea that at night the runway may look much closer than it actually was and this caused a pilot to descend too aggressively. Kuhlman also warned pilots of approaches into runways when there is little contrast between the runway and adjacent terrain.

Hartman and Cantrell (27), in 1968, wrote a short but detailed paper on the "Psychological factors in 'landing short' accidents." Approaches to landing over water and texture issues were discussed but no mention of a BH or even featureless terrain type environment was presented.

In 1969, Kraft and Elworth (32) reported that prior to 1967, nearly 16% of major aircraft accidents were over dark terrain at night and towards airports with well-lighted cities. The phrase BH however was not used.

Hasbrook (28) in 1971, stepped readers through a landing, addressing pilot instructor-type tips. He addressed a clear but moon-less night, and the dangers of a BH airport, specifically using the phrase. Hasbrook suggested techniques to avoid BH approach errors.

In 1974, a Pan American World Airways commercial airliner crashed 1,026 m short of Runway 05 at Pago Pago International Airport in American Samoa (46). That formal report may have been one of the first that used the term BH in the investigation.

Kraft (31) in 1978, assessed a series of accidents and found that they all occurred over dark terrain/water, all were operating under visual conditions (not using instruments), and all had no malfunctions with instruments (altimeters were operating). His conclusion was that a profoundly serious visual illusion was involved. Kraft noted that despite the fact that all the pilots were confident in their ability to fly via visual reference to the runway, flying over dark terrain toward lights induced the pilots into thinking they were higher than they actually were (over-estimated their PAD). This resulted in the pilots inappropriately descending to correct their feeling of being too steep. Kraft used the term "dark hole" to describe the terrain below the pilots and "flying the null" to mean the pilots were maintaining the same visual angle for the

runway as they descended towards it. Kraft also used the term BH to refer to another study and its experimental set-up.

In 1979, Lewis and Mertens (35) made reference to BH approach conditions during their research on VASI comparisons. They assessed different types of VASIs to determine which ones best-assisted pilots to fly the desired GP to landing. The authors also combined for a series of research articles on visual SD (43, 44). That same year, Mertens (42) reported a possible explanation for the BHI was due to an equidistance tendency (22).

Perrone (57) in 1984, specifically addressed the BH approach to landing by formulating a model of visual slant misperception, calculating PAD. Given distance to the runway, runway width and length, his model calculated the PAD versus the actual angle to descent.

In the 1990's, BH approach articles became common place. For example, Schiff (60) wrote an article for the *Boeing Airliner*. He began his article stating that in the 1970's, BH approaches were a "significant hazard to airline operations." Schiff then listed current airports that still can provide a BHI to pilots such as Seattle, Honolulu, and Las Vegas. He reviewed the conditions in which a BH approach may be encountered and ways to overcome (avoid) the illusion. In 1999, an article appeared in FSF's Human Factors and Aviation Medicine journal detailing human perceptual limitations in night flying and specifically addressed the BHI (69).

In 2000, the *IEEE Engineering in Medicine and Biology* magazine centered an entire issue on aviation SD to inform readers of a cause of aviation mishaps (34). The issue, which also had the article on the USAF survey (62), briefly presented visual and vestibular illusions however, in discussing shape/size/background constancy and altitude/distance misperceptions failed to specifically mention the BHI (34).

In 2004, the US Navy dedicated an entire issue of their aviation safety magazine, *Approach,* to the topic of SD. One article reported that out of a total of 120 US Naval Aviation mishaps in fiscal years 1997 – 2002, 22 were SD mishaps costing 23 lives and $475M (68). The Flight Safety Australia magazine, 2005, featured an article entitled "Eyeball Error," that presented the BHI and issues associated with it. That article stated, "for complex reasons, not all of which are currently understood, you may fly an approach that is too low" (52).

The first book dedicated to aviation SD was published in 2004. In the book, Previc (58), estimates that half of all SD mishaps have visual misperception problems. In an entire chapter on visual illusions in flight, the BH approach was categorized under "absent ambient vision" and the theories and work of Perrone (57) and Mertens and Lewis were presented (44). In by far the most current and thorough presentation of the BHI, Previc recognized Perrone's (57) work on size/shape constancy and form ratio as the leading theories for pilot misperception.

In 2006, two articles appeared addressing aspects of the BHI. One detailed events of a classic BH set-up -- night visual approach to landing, a long straight-in approach, up-sloping terrain, and in a remote location (24). The incident shared was a wide-bodied aircraft saved from CFIT by a terrain awareness and warning system (TAWS) with a "TERRAIN, PULL UP" warning 76 m above the ground, 2.8 km from the runway. In the second article, Chamberlain (11) addressed the BHI and perils of night flying. His perspective was operationally orientated for what actions a pilot can take to mitigate the risks of night flying.

Today, the Federal Aviation Administration has a web site and numerous safety brochures for the continued education of pilots concerning visual SD (15). One of the brochures, "Spatial Disorientation: Seeing is Not Believing" discusses the BHI. The brochure describes the

illusion as occurring when over dark terrain lacking in peripheral cues and without a discernible horizon inducing a pilot into a steep PAD.

Questions Remain

Calvert (7) stated that the illusion of a featureless terrain resulted in the runway appearing to "float in space" due to a lack of texture. According to Calvert, terrain texture contains objects of known size (due to size-distance constancy) and the farther the distance the smaller the visual angle. Thus, terrain provides not only horizontal distance but also height information.

Kraft (31) offered a constant angle theory of the city lights beyond the runway as also promoting the perception of a BH. Schwirzke and Bennett (61) however, conducted a re-analysis of Kraft and Elworth's (32) results regarding BH approaches and questioned their conclusions. They specifically challenged Kraft and Elworth's (32) assessment of the data which was "not consistent with the curvilinear, low-altitude approaches that would be generated by pilots attempting to maintain a constant visual angle to the runway" (61, p. 574). The constant visual angle also doesn't match reality of a runway image expanding isotropically. Schwirzke and Bennett conclude by stating, "the fact remains that what pilots use as cues for landing is still a mystery" (p. 575).

Pendleton (56) explained the basis for concave trigonometry of inscribed angles intersecting the same arc as being congruent; clarifying the phrase "flying the null." She concluded her article with, "there are many other theories about factors that may contribute to the black hole illusions. Some are more believable than others, but the thing you MUST believe is that if the conditions are right, you can be fooled by the black hole illusion" (p.4).

Parmet and Gillingham (55) describe the featureless terrain illusion in various ways that could all apply to the BHI. They cite the inability to estimate height above the ground because

of the lack of focal vision cues (absence of terrain features) results in failing to estimate appreciable sized objects and height above the ground. Also, a lack of ambient cues may induce pilots to descend on a shallow glidepath due to the lack of ground surface orientation and/or pilots feel stable but the runway itself appears malpositioned (similar to Calvert's term "float"). Still other reasons for the illusion are due to size/shape constancy misperceptions. And finally, Parmet and Gillingham discuss the BHI in reference to Kraft's "flying the null" and distant city lights inducing a pilot into a short landing.

Many studies have made reference to the BHI from a variety of distances (19). Calvert (9) referred to the BH effect occurring the last 23 m above the ground. Kraft (31) started subjects at 32 km and stopped 7.2 km from the runway because this point was 1.6-km prior and 76 m above where ground motion cues would assist with altitude control. Mertens and Lewis (44) started at approximately 7.4 km and stopped 2.4 km. Lintern and Walker (36) collected data to only 697 m from the runway. Pendleton (56) claimed the BHI disappears 3.2 – 4.8 km from the runway. Palmisano and Gillam (54) only assessed the final 30 – 91 m above the runway. A leading theory of the BHI is Perrone's (57) model but it is limited to a short distance from the runway (58).

Various distance descriptions of the BH phenomenon also exist. The 2001 Falcon crashed 8.3 km from the runway, the 1997 St. Thomas island crash was 4.8 km, whereas the 1974 crash in Pago Pago was 1,025 m short, and the 1999 USAF C-130 crashed 881 m short. The 2002 FedEx crash profile depicted the aircraft beginning to go below the desired 3 degree GP around the 5.6 km point and crashed 472 m short of the runway.

Even accident investigations have varied on their analysis of BH conditions. The 1974 Pago Pago accident openly discussed the BH effect experienced by the pilots while on a short

final for landing. Yet, in 1997, the crash in Guam by a 747, seemed to have occurred in an obvious BH environment throughout the approach though it was not specifically mentioned by the NTSB in their report. The Guam environment was also similar to the Tallahassee, FL crash in 2002 in which the NTSB very specifically addressed the BH conditions contributing to the accident. And finally, the USAF AIB's assessment of the 1999 C-130 crash cited pilot errors for succumbing to SD.

DISCUSSION

Certain areas of study are perceived as thoroughly researched and documented, thus removing them from further inquiry. Unanswered question however may still remain. Aviation visual perception in general is not well understood (18, 19, 36, 52) and the BHI is one such over-looked research phenomenon that is also not fully understood. The inconsistencies in the research and accident investigative reports demonstrate that there is still much to learn about visual SD.

There is yet no consistent explanation of and no agreed upon distance when and why the BHI may occur. As different as the various explanations are, however, the one common thread taken from numerous BH discussions is the absence of terrain to provide size, distance, depth, and orientation cues for ambient vision. Pilot education has attempted to reduce the effects of visual SD, but it is difficult to de-bias a compelling visual illusion despite objective knowledge of the difference between reality and illusion (67). The explanations and suggestions regarding visual SD have not changed in nearly fifty years. Pilot limitations are acknowledged during night visual approaches as well as the preference to abandon instruments and proceed visually (2). Questions still remain however, from Hasbrook's 1975 analysis (29) to today as acknowledged by recent USAF SD surveys (38, 62).

Pilots are overconfident in their visual capabilities because they do not realize how compelling these illusions are. To couch visual SD as "pilot error" due to a poor instrument cross-check fails to address the fundamental cause of the problem -- a better explanation would be "human perceptual limitation." As demonstrated in the 2002 FedEx BH accident and the near-CFIT mishap by the F-16, VASIs/PAPIs were available yet the pilots failed to correct their GP based on their indications. More airfield environmental information needs to be presented as well as improved instrumentation to pilots that recognize their preference for a purely visual approach based on still unknown salient visual cues.

Finally, visual SD needs to be further researched due to the increased amount time pilots spend in an environment most conducive to SD. Gillingham (21) made this observation 15 years ago and, since then, technological advancements have further increased the ability for pilots to fly at night. He called for research into visual SD, "because several types of solution[s] to the SD problem depend on visual orientation information" (p. 304).

CONCLUSION

Calvert, in the 1950's, advocated approach lighting systems to better aid pilots' vertical and lateral awareness. Today, vertical awareness issues during an approach to landing have not been solved. Synthetic vision systems (SVS) are the newest technology to address CFIT concerns (5) and they are also being combined with TAWS (6). Before research gets ahead of itself, questions must still be answered regarding salient visual cues in both rich and impoverished visual scenes. As Mertens (43) noted back in 1981 when addressing the BHI, "a pilot only has to crash short of the runway once in his career to destroy his and his passengers' lives!" (p. 384). SVS and TAWS can help, but those technologies still don't get to the heart of the issue regarding an understanding of visual perception in the aviation. Research needs to take

the "illusion" out of the BHI (26) and help pilots become more knowledgeable regarding their ecological perception.

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DISCLAIMER

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APPENDIX

Historic Operational Recommendations for Night Visual Approach to Landings

1. Kuhlman (33) clearly gets to the point, "Never, but never, make a straight-in landing on a clear, dark night. A rectangular traffic pattern will keep you oriented as to distance from the runway and avert this common night illusion."
2. Hartman & Cantrell (27) presented psychological factors in approach to landing mishaps and stated (a) "strong evidence that the pilots were motivated by a great desire to complete the approach" and (b) during the accident "the captain is usually in control."
    a. According to a NTSB report (47) of flight-crew involved major accidents from 1978 – 1990, the captain/senior pilot was flying in 30 of 37 accidents, 81%. The NTSB (47) report and Berman (3) both concluded that a senior pilot would be a more proactive communicator to monitor and challenge a junior pilot during an approach.
    b. Emphasize the junior pilot fly or ensuring an environment exists that promotes the junior pilot can assertively challenge a senior pilot's actions & promote aborting a bad approach and establishing "stabilized approach" criteria.
3. Kraft & Elworth (32) suggested the following to mitigate the risk of BH approaches
    a. Avoid a long straight-in approach.
    b. Avoid having a navigational facility that is not located on the airfield.
    c. Ensure the airfield has adequate lighting and landing aids available.
4. Hasbrook (29) listed some basic principles to avoid approach to landing mishaps:
    a. Remain alert to and compensate for, the tendency to fly nighttime and low-visibility approaches at too flat an angle and too low an altitude.

b. Monitor altitude, vertical speed and airspeed instrument readings as often as possible during the last 60 seconds of the approach.

c. Determine and use a 50-foot minimum threshold-crossing altitude.

d. Resist the desire to pitch down and duck under in response to illusions created by visibility conditions

e. Abort the approach and go around if things don't look quite right.

5. Schiff (60) suggested having a short final approach segment if possible, of 2-3 miles.

6. Considering the "Why the misperception of PAD?" hypothesized reasons is another way to address the BHI and mitigate risk.

    a. Flying a non-descending path directly to and over the runway at pattern altitude eliminates problems such as (a) size/shape constancy of the runway because the pilot is flying directly over the runway of known dimensions, (b) familiar/relative size problems are also accounted for by flying over the runway, (c) no bias to over-estimate visual angles in the medial extent since the runway is viewed from above, (d) terrain cues are still absent but the airfield environment can be seen from above in terms of taxi-way lighting, ramp lighting, and the entire runway outline, and (e) lack of distance cues is resolved by knowledge of the runway length and a rectangular or overhead pattern can be based on runway (when to begin the turn to final) as well as timing techniques.

    b. Improve the ALS on the runway with knowledge that simply adding an ALS may increase the perception of the runway's length if flying a long, visual straight-in and further promote a BH approach (45). Hence, the addition of an ALS would benefit instrument approach transition to landing and visual overhead/rectangular pattern visual perception, but not a night visual straight-in.